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Workshop on "High Speed Body Motion in Water"

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Van 1 tot 3 september 1997 is er in Kiev een workshop gehouden over “High Speed Body Motion in Water”. In opdracht van de Koninklijke Marine hebben ir. J. Windt van het Marin en ir. C. Volwerk van TNO-FEL deze workshop bijgewoond. De workhop had een internationaal karakter met deelnemers uit Rusland, Ukraïne, Verenigde Staten, Spanje, Italië, Frankrijk, Turkije, Duitsland, Israël, Noorwegen en Engeland. Een van de doelen was dan ook om nieuwe contacten te leggen tussen enerzijds de Europeanen/Amerikanen en anderzijds de Ukraïniers/Russen.

De workshop was opgedeeld in vijf sessies: “Hydrobionics”, “Boundary layer flows”, “Supercavitating flows”, “Air-water penetration” en “Control of cavitation”, waarin zowel theorie als praktijk aan bod kwamen. Hieruit bleek dat er veel gebruik wordt gemaakt van numerieke simulatieprogramma's om de diverse problemen te lijf te gaan. Om een idee te krijgen van de benodigde parameters worden aanvullende experimenten gedaan. Op deze manier wordt meer inzicht verkregen in het gedrag van opjecten die met hoge snelheid door het water bewegen. Experimentele resultaten van zowel de Oekraïniers als de Amerikanen lieten echter zien dat het behoud van stabiliteit nog steeds een groot probleem is.

Contents

1. Introduction

1.1 Introduction

From 1-3 September 1997, a workshop on 'High Speed Body Motion in Water' was held at the Institute of Hydromechanics, Kiev, Ukraine. In this report a summary is given of the presented lectures.

1.2 The city Kiev

The workshop was held at Kiev. This is the capital of Ukraine, its political, economic, commercial and cultural centre. Ukraine is one of the youngest states in modern Eastern Europe today. For many years it was a republic of the former Soviet Union.

Although Kiev is the capital of a new country, at the same time, it is one of the oldest cities of East Europe. The different ancient sources show that the city has existed for more than fifteen centuries. In Kiev's streets, you can see both the monuments of its ancient past, which are currently being restored to attract more tourists, and the landmarks of a newly independent country. Modern Kiev has wide boulevards lined by majestic trees, beautiful parks with lovely flowering plants, and monumental buildings, reflecting the graceful elegance of different architectural styles and periods.

Kiev is the science centre of Ukraine. Many new research directions are now developing in a number of Institutes of the National Academy of Sciences and Universities. A lot of International Conferences take place in Kiev every year.

1.3 General impression of the workshop

The participants of the workshop came from France, Germany, Israel, Italy, Norway, Russia, Spain, Turkey, Ukraine, United Kingdom, United States and The Netherlands. The workshop was held at the Institute of Hydromechanics. At the start of the workshop a lot of Ukrainian people were present, because this was the first international workshop held at their institute. The atmosphere was friendly, probably due to the fact that a lot of researchers already knew each other. The average age of the participants was about 45 years and some of them were already retired and were present on invitation.

Most lectures were of good level, presenting theoretical as well as experimental results. The lectures given by the Ukrainian and Russian were mostly in Russian. Interpreters were available, but could not handle all technical terms and talking

speed, which made it difficult to follow. The days were packed with lectures, giving little time for lunch. Lunches therefore were served at the Institute.

1.4 Outline of report

The workshop was divided in five sessions. In this report, the outline of the workshop will be continued. This means that in Chapter 2 the hydrobionics session is treated, in Chapter 3 the boundary layer flows, in Chapter 4 the supercavitating flows, in Chapter 5 the air-water penetration and in Chapter 6 the control of cavitation. In Chapter 7 the conclusions towards this workshop are given.

2. Hydrobionics

As a result of evolution, hydrobionics (which means sea-life) have developed an economical energy expenditure and efficient drag reduction. The majority of high-speed hydrobionics are just as good as American submarines as to speed of motion, and some even have speeds more than those of technical objects. To gain benefit from this, dolphins are studied extensively at the Institute of Hydromechanics. The hydrobionics session dealt with some of the methods of propulsion and drag reduction found in nature.

P.R. Bandyopadhyay from Newport, USA, discussed experiments with a small rigid axisymmetric body propelled by a pair of flapping foils [1]. The body (1 m long with a 7.6 cm diameter) moved up to 0.8m/s. Two flapping modes were investigated, waving and clapping, which can be found in nature by fish hydrodynamics and wings (i.e. butterflies and moth) respectively. In Kiev research is also done on man-sized objects, using a fish-like tail. This tail consist of two plates, making a flapping or waving movement. For the designed '(under)water-bike' this movement is induced by manpower. It causes a lot of noise, but it works.

S.A. Dovgiy from Kiev, Ukraine, examined the non-linear effects of the oscillating wing performing the function of a propeller [5]. Computations using the non-linear theory are compared to the linear theory and experiments. L.I. Korennaya from Kiev, Ukraine, discussed experimental results with respect to wave plate motion [6]. The wave plate models the motion of fish.

V.V. Babenko from Kiev, Ukraine, discussed the hydrobionics principles of drag reduction [3]. Babenko performed experimental research on dolphins. Dolphins move at high speeds with much lower drag than the corresponding rigid body. He studied the influence of swimming speed, non-steadiness of the flow, unusual method of thrust creation, specific structure of body surface onto the body system. Experience is used to develop analytical and experimental models of the dolphin-skin. The models are used to examine the characteristics of viscoelastic coatings which significantly reduce the drag in water. V.I. Merkulov from Novosibirsk, Russia, discussed the analytically research of the generation of vortices to decrease hydrodynamic drag [2]. A travelling wave on an elastic body surface works as a mechanism for the formation of periodic vortex structures as is observed with dolphins. The drag reduction consists of the substitution of slipping friction by rolling friction. G.A. Voropaev from Kiev, Ukraine, discussed numerical calculations and quantitative characteristics of the boundary layer flow over viscoelastic coatings [4]. He showed that viscoelastic coatings can lead to noticeable (by 10-12%) friction drag reduction.

2.1 Session summary

This session showed that we can learn a lot about sea-life. How they move, how they create thrust, how they reduce drag. Research is done with respect to artificial fish-like objects, hydrobionic propulsion systems and hydrobionic principles of drag reduction. It resulted in man-sized objects with fish-like tails and viscoelastic coatings to reduce drag. However, there is still a lot of research to be done before, for example fish-like objects, with the same economical energy expenditure and efficient drag reduction as those resulting from evolution, can be build.

3. Boundary layer flows

Another result of the study on dolphins for example is that it is found out that the skin of the dolphin actively reacts on pressure distribution, and influences the boundary layer flow around the dolphins body. A significant drag reduction is obtained by delaying the transition to turbulence by dissipation and reducing the energy in the turbulent boundary layer. The "Boundary Layer Flows" session dealt with the experimental research, numerical modelling and controlling of the boundary layer flow.

V.V. Babenko [9] from Kiev, Ukraine, discussed the boundary layer flow over rigid and elastic plate's. Extensive experiments have been conducted to determine parameters of the laminar, transitional and turbulent boundary layer regions. R. Bannasch [13] from Berlin, Germany, discussed the experimental study of the motion of live Penguins and body of rotation derived from penguin data. Live penguins as well as the body of rotation revealed very low drag coefficients. The paper discusses the flow phenomena eventually responsible for this low drag. V.G. Belynsky [17] from Kiev, Ukraine, discussed the experimental research of the movement of a wing above a wavy surface of water. The experimental installation exists of a wing section moving above a rigid wavy or flat plate. Lift coefficients have been obtained for various configurations: wing sections with or without a flap, wavelength of the wavy plate and distances between the plate and wing.

B.J. Cantwell [7] from Stanford, U.S.A, discussed the boundary layer flow over a flat plate. By analysing Direct Numerical Simulations he relates the Reynolds shear stress to a new scalar quantity. Experience can be used to develop new turbulent models. E.A. Shkvar [10] from Kiev, Ukraine, discussed the mathematical and numerical modelling of the boundary layer flow. The half-empirical algebraic turbulence model is used to calculate analytically and numerically the boundary layer characteristics. Results have been compared to experimental data. V.T. Grinchenko [11] from Kiev, Ukraine, discussed Direct Numerical Simulations of the boundary layer flow. The mathematical approach, based on the Model of interaction of Slow and Fast disturbances (SFM), is described in detail. The method is used to calculate the phase speed of typical boundary layer structures propagating in longitudinal direction. The research is a co-operation of the Institute of Hydromechanics in the Ukraine with the Louisiana Technical University in the U.S.A. U. Bulgarelli [16] from Rome, Italy, discussed numerical calculations of a wing section moving along an interface of two fluids. Steady and unsteady, linearised problems are solved, however the non-linear solution is not yet obtained. It is concluded that reference solution and/or experimental data is needed to be able to assess the ability of the applied method. Moreover non-linear solutions are necessary.

W.S. Saric [8] from Tempe, U.S.A., discussed the control of vortices in the turbulent boundary layer by surface roughness and surface curvature. Concave curvature is destabilising however convex curvature can be stabilising. Distributed surface roughness can inhibit growth of critical wavelength and hence delay the transition to turbulence. E.I. Nikiforovich [12] from Kiev, Ukraine discussed analytical research of the boundary layer development. By using an asymptotic analysis of the Navier Stokes equations the development and propagation of the vortical boundary layer structure is examined. V. Gorban [15] from Kiev, Ukraine, discussed the numerical study of the dynamics of vortices in the near wall region. Vortices, induced by vortex chambers, are used to reduce drag by preventing or reducing global separation of the flow. The topology of a flow can only efficiently be influenced using vortices if stationary (unstable) vortices are generated by active control systems.

3.1 Session summary

An important aspect of high speed body motion in water is the frictional drag of the body. The boundary layer flows session discussed mechanisms to reduce this drag, for example vortex chambers. Moreover some aspects with respect to ekranoplanes have been discussed. Experimental research, numerical and analytical calculations of the turbulent boundary layer flow have been presented.

4. Supercavitating flows

At the Institute of Hydromechanics a lot of research is done on high-speed supercavitating motion. They have several devices for their experiments [20]:

- a 35 m launching tank with electrochemical catapult, this catapult uses gas pressure. This gas comes free after decomposition of water;
- a vertical tank to investigate water entry;
- two hydrodynamical tunnels of the open type:
  1. a small hydrodynamic tunnel. Its working section is 0.34 x 0.34 m, the working part length is 2 m and its mainstream velocity is 9 m/s;
  2. a big hydrodynamic tunnel. Its working section is 0.5 x 0.5 m, the working part length is 4 m. The maximum velocity for this tunnel is 30 m/s.

The maximum velocity of a high speed object, ejected by the Ukranian 'catapult' is 1360 m/s. During its 35 metres trajectory the object loses 40% of its initial velocity. The problems which occur are that the electrolysis gas energy is hard to handle and sometimes destroys the catapult and that the cavity around the object sometimes closes from behind and destroys the object itself.

At NUWC also a successful high speed launch has taken place (17 July 1997). Here the object travelled 17 metres with an initial speed of 1550 m/s. It was launched using a fully submerged gun (depth 4 metres). Main problems here were the launcher alignment and instabilities of the object occurring at speeds above 1 Underwater Mach.

When moving in a vapour or gas cavity, the cavitating object loses its main advantage of motion in fluid and needs dynamic means of stabilisation inside the cavity. To analyse the stability during high-speed motion, a program is developed at the Institute of Hydromechanics, called STABILITY [20,22]. The basis for this program is formed by a few simple relations given by A.D. Vasin [20]. The program enables to calculate the cavity shape and dimensions at subsonic and supersonic velocities, if the cavitator drag is known at a given Mach number, for given model shape, mass, initial motion and under action of external perturbations. With this model is it shown that self-stabilisation in a supercavity is possible due to the specially designed, so called statically stable shape of the cavitator. Concave wedges belong to the self-stabilising cavitators.

In the USSR, since 1980 research is done on supercavitation in compressible fluid. They have designed a numerical method of calculating compressible subsonic and supersonic flows over a wide range of cavitation numbers [21]. The results of the numerical calculations were checked on the satisfaction of the mass and impuls conservation laws. These tests showed good accordance.

At the Institute, several computer simulations are developed [22]. A necessary condition here were simple mathematical models and fast computation algorithms. The developed programs are of two kinds:

1. Programs enabling to compute the cavity shape and all necessary flow parameters for various combinations of parameters quickly, for example: SUPERCAVITY.
2. Programs enabling to carry out "the computer experiment" with dynamic display of non-stationary cavity shape and other necessary information during runtime, examples: ENTRY, STABILITY, PULSE and DIVE.

SUPERCAVITY is developed to compute the influence of the model design. This program is supported by a comfortable user interface. It calculates the model impact load, the parameters of motion and the cavity shape at any mark of the trajectory x and the width of the circular clearance between both the model and the cavity boundaries distribution.

G.V. Logvinovich [18] and M. Tulin [19] presented a very global historical outline of their work done in the USSR and USA respectively. Paper's were not available, but can probably be found in open literature.

V.V. Serebryakov [23] first presented a very global outline of the theory concerning supercavitation. Finally he discussed an effective method for the calculation of slender cavities (1990). However all sheets contained a dozen of formulas and were shown only a few seconds. Moreover the presentation was in Russian and hardly translated. Therefore no detailed abstract can be given.

4.1 Session summary

As may be concluded from the above, a lot of attention is paid to supercavitating flows, theoretical as well as experimental. Future research will aim to create more stable objects, travelling at higher speeds over longer distances. Computer models will play an important role in this for creation of a perfect model. Some participants were interested in buying the Ukrainian programs.

5. Air-water penetration

This session dealt with the problem of an object entering the water surface. The lectures treated ships movement, water entry of a wedge, experimental results with ejected and supercavitating models. All of these point to the same problem, the large loads that can occur during impact between body and the water surface, which can cause extensive damage and the generated spray, which causes a significant resistance.

O. Faltinsen from Norway [24] discussed the problems of a moving ship. Impact between the water surface and a ship, i.e. slamming, can cause important loads on a vessel. He mentioned a simplified hydrodynamic model for water entry of a two-dimensional body presented by Zhao, Aarsnes and himself. This model is numerically robust and the quality of the predictions are believed to be satisfactory for engineering applications. He generalised this two-dimensional numerical method to a simplified three-dimensional method for water entry of ships or other structures and validated this with tests for spheres and cones.

The two-dimensional water entry of a wedge at constant vertical speed into a free surface initially at rest is discussed by R. Cointe [25]. He presents the Mixed Eulerian Lagrangian method, which has been tested and thoroughly validated for numerous applications related to wave generation. The water entry problem however, has a strongly non-linear character and therefore the application of the MEL method is still delicate. Difficulties to model the flow correctly are related to the numerical treatment of the flow in the vicinity of the intersection point. The analysis that was described in the case of a wedge can be extended to arbitrary geometry's as long as the angle between the tangent to the body and to the free surface remains small. Work is underway to extend these numerical results to water entry for a body of arbitrary shape.

The experiments discussed were carried out at the Institute of Hydromechanics. They implied the stability of a supercavitating slender body during water entry and underwater motion and the reduction of the overload on a body entering water at high speed. They were performed by S.I. Putilin [27] and V.T. Savchenko [29]. The main aim of the experiments conducted by Putilin was to investigate the processes that take place when a body enters the water and the influence of different body features on these processes. The maximum velocity of the ejected bodies was about 20 m/s. When entering the water surface, typical forms of motion were distinguished:

- the model motion changes little after water entry;
- the model reflects from water surface and moves in nearly previous position in air;
- the model touches water surface and begins to rotate about its nose, thus entering the air again, with its aft end being in front;
- the model enters water but changes its motion significantly.

Special models consisting of two parts -fore and aft- were constructed to investigate underwater division of a body into two parts. The aft part of the model contains a spring device that ensures division of the model parts some time after the model has been ejected by the catapult. With this, the velocity of the fore part increases during the division. The resistance of the fore part was great however, and its velocity diminished quickly.

V.T. Savchenko did experiments with bodies entering the water surface at high speed [29]. With these speeds, a supercavity is formed around the body. The supercavity permits us to solve the following problems:

- reduction of the hydrodynamic drag of bodies;
- reduction or removal of the destructive normal loads on bodies

Savchenko designed a foil which operates effectively in two media. This foil holds patent.

O.P. Shorigin (presented by A.D. Vasin) from Moscow investigated the "Spray Influence on the Drag of a Gliding Body" [26]. The contribution of spray to a ship's resistance can be substantial (up to 40 %). Wedge shaped objects have been developed which enter the water almost shock free and hence generate almost no spray jet. A paper was not available.

M. Arnaud from France discussed numerical calculations with respect to cavitation [28]. The numerical code consisted of a cell centred finite volume method, using the Volume Of Fluid (VOF) method to model the free surface. Time averaged Navier-Stokes equations including gravity were solved, however presumably no energy equation is included. A short discussion did not reveal whether or not only phase transition from gas to liquid is neglected. Results were presented of calculations of the implosion of a cavity bubble. A paper was not available.

5.1 Session summary

To know the loads on an object while entering the water is very important. Large loads during impact can cause severe damage. Numerical simulation programs are developed to examine these loads, for both low and high-speed moving objects. At the moment these programs use simplified equations and/or two-dimensional symmetric bodies. Work is underway to extend these programs to water entry for bodies of arbitrary shape. By means of experiments, at the Institute, they investigate the processes that take place when a body enters the water and the influence of different body features on these processes. They also examined bodies consisting of two parts.

6. Control of cavitation

The 'control of cavity' session treated the scaling problem of the cavitation phenomena, ejection of a polymer to reduce cavitational effects, supercavity control and prediction of the sound generated by supercavitating objects.

The prediction, or better, the control of cavitation to avoid damage is the aim for the design of hydraulic machines and structures. Model tests are necessary because cavitation still evades exact theoretical prediction. A. Keller strives to solve the problem of scaling cavitation phenomena and its technical relevance [31]. He has seen numerous examples where the model was observed to be cavitation free at design operating conditions, but the prototype suffered extensive cavitation to severe damage under similar conditions (from ship building to pump industry). The cavitation theory assumes, that the cavitation phenomena at the model and the prototype for geometrically similar bodies are identical at equal dimensionless cavitation index, irrespective of variations in physical parameters like body size, flow velocity, temperature, type of the liquid. The experiments Keller has done, imply that cavitation is extremely sensitive to water quality. With this in mind he gives a new definition for the dimensionless cavitation index.

Experimental results performed by ejecting a polymer (USS301) from an orifice situated at the tip of an elliptical hydrofoil are reported by D.H. Fruman from France [32]. Since tip vortex cavitation is generally the earliest form of cavitation to occur, much attention has been devoted to investigate the conditions under which it occurs. Fruman demonstrated that the conditions for tip vortex cavitation occurrence are substantially modified by the ejection of very small flow rates of the polymer solution. The ejection port was situated just at the foil tip and has a diameter of 1 mm. Ejection test were conducted with aqueous solutions of Poly(ethylene) oxide POLYOX WSR 301. Ejection of the polymer in the vortex core results in a decrease of up to 30% in the cavitation numbers. Thus allowing the free stream velocity to be increased up to 15%. Ejection of pure water did not have any influence.

Yu. D. Vlasenko discussed the control of cavity parameters at supercavitating flow [34]. The possibility of supercavity control is of interest from a point of view of the optimal flow regime maintenance for unsteady conditions. Vlasenko has build a body consisting of two elements. One of the elements, the outer body, can be moved about the rigidly fixed second element, the central element, in the longitudinal direction. This gives the possibility to vary the cavity characteristics and thus the drag. The conducted experiments permit to detect some features of the cavity section formation due to specific configuration of local parts of the cavitating edge of a nozzle. The possibility of control of the supercavity parameters by varying the drag coefficient of the cavitating body at preservation of the constant cavitating edge has been experimentally shown.

The accurate prediction of the sound field generated by bodies moving in water is important to control sources and reduce noise [35]. The available models that describe the cavitation flows do not give an adequate picture of the flow in all domain. So the data on noise in cavitation flows are based on experimental measurement. Results show that due to the cavitation, a sound field is produced, which has its main peak between 400 and 950 Hz and has a level of 61-96dB.

V.V. Pilipenko discussed the application of a cavity generator in combination with a drill head used for oil drilling [33]. Controlled, periodic, cavities and as a consequence high periodic pressure fluctuations improved the drilling process.

6.1 Session summary

Cavitation is from one side a big problem, causing severe damage. The new definition for the dimensionless cavitation index introduced by A. Keller is therefore a good tool to investigate scaling problems. Ejection of a polymer helps to reduce cavitation, but does not cancel it. From the other side cavitation is greeted thankfully. Thanks to cavitation, drag forces are reduced and higher speeds obtained. Controlling the cavitation, for example with the two elements, is of great importance. The sound however, is still not controlled.

7. Conclusions

The workshop intended to improve the contacts between European/American and Ukrainian/Russian scientists. Five different sessions with respect to high speed body motions have been held. Almost all subjects showed to have a long scientific history, on which both Europe/USA and Ukraine/Russia have been working separately. During the three days workshop nearly all participants attended the presented subjects enthusiastically. Many contacts on scientific level are made between both parties, making the workshop a successful one.

The hydrobionics session made clear that most research is done on the surface of living animals. This may result in viscoelastic coatings which have a wide range of application.

The physics of turbulence are still not fully understood. The boundary layer flow session discussed the extensive experimental studies and numerical simulations to clarify the principles of viscous drag reduction. These principles seems to be very specific which make them hard to apply in practical situations. The movement of a wing over a water surface is also treated during this session. Examples of planes using this wing-in-ground effect are found on the Internet; see appendix A.

With respect to the supercavitating flows the following. As well in the Ukraine as the United States much research is performed on ejection of supercavitating objects with an initial speed greater than 1 Mach (1 Underwater Mach equals 1450 m/s). At the moment these object are about 20-30 cm long, but have a very unstable trajectory and still suffer of great water resistance. Numerical simulations done by the Ukrainian may help to create a more stable shape. However, since the objects are to small to produce their own thrust, expected ranges are of the order of some hundred metres. Active creation of cavitation is only slightly treated. Here main problems are also the stability of the object. However, if this problem is overcome, speed of the objects increases and longer ranges may be achieved. In fact the subject is so specialised that without any additional research in literature nothing can be said about future expectations.

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9. Signature

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Development of Ekranoplans

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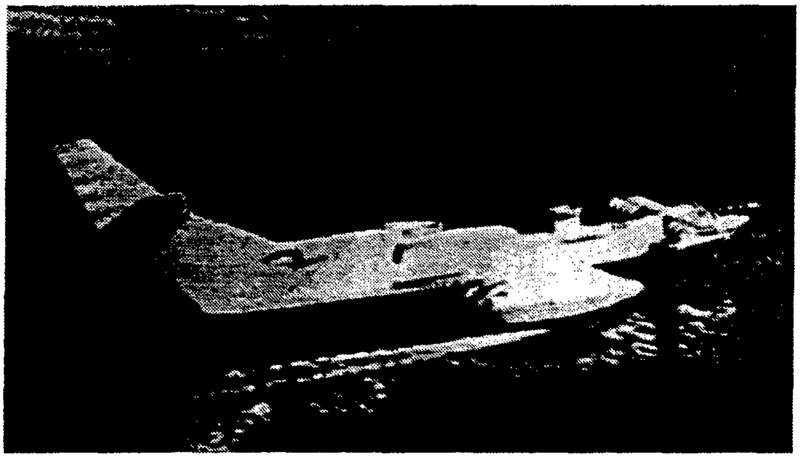
Russian effords in creating a Wing-In-Ground effect vehicle started in 1960 at the Central Hydrofoil Design Bureau in high secrecy. This bureau was engaged in designing hydrofoil ships at that time. Their first WIG vehicle (the SM-1) was an attempt to create an even faster vehicle for operation over water, therefore it is not surprising that the SM1 had its two wings set up in a tandem configuration, which is similar to a hydrofoil ship.
The three ton SM-1 showed some problems: bad manoeuvrability and an extremely high take-off speed. The latter was later found to be a typical problem for WIG vehicles. The Russians dropped the tandem concept, but the German Jörg later successfully built a number of tandem WIG vehicles.

Rostislav Alexeiev

The developments at the Central Hydrofoil Design Bureau were lead by Alexeiev, who is now called the father of the Ekranoplan, which is the Common Russian name for a WIG vehicle. In 1962 Alexeiev designed the first Ekranoplan as we know it now, the SM-2. This five ton vehicle had a low main wing and a T-tail. The problem of the high take-off speed was solved in the SM-2P7 version by a principle called air injection in Russian and Power Augmentation in English.
Initially a lot of stability problems were encountered, but they were minimised by installing an extremely large and high T-tail. This stability is also a typical WIG vehicle problem.

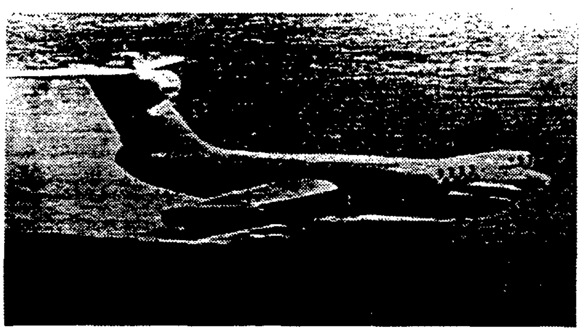
The Caspian Sea Monster

When the new configuration of the Ekranoplan passed all flight tests successfully, a very ambitious program was launched in 1963, the KM (Caspian Sea Monster). The 550 ton KM was way ahead of its time, being 100 times heavier than the SM-2. The object of building such a large craft was to investigate the concequences of size on the concept of the Ekranoplan. A number of experimental vehicles were built during the design and manufacture of the KM, in order to answer certain questions about stability, manoeuvrability and amphibious capacity.



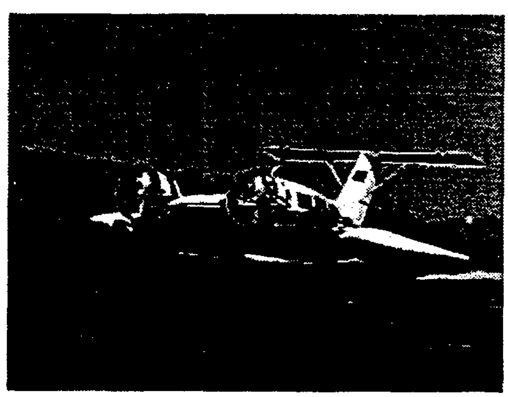
Among these test vehicles were the SM-5 and SM-8 (photo right), which were built and tested in the period 1964-1966. The KM was finished in 1966 and successfully tested in 1967-1969 it proved to be capable of stable flight up to speeds of 500 km/h and heights of 20 m. The maximum wave height for operating the KM is 3 metres. Eight KM's are reported to have been built, all of them were different (size, wing layout).

A spin off of the KM project was a design with a turboprop engine at the top of the fin and two turbofans in the foreward fuselage, providing an air cushion under the wing at take-off, so called Power Augmentation. Around 1970 the 20 ton SM-6 Utka (Duck) was the first vehicle of this configuration to be built. The well-known A.90.150 Orlyonok (Eaglet) was designed and built in 1972 after successful testing of the Utka. (Although some sources claim that the Utka was a scaled down Orlyonok).
The size Orlyonok is comparable to that of the McDonnell Douglas MD-11 and the maximum take-off weight is 125 ton (usually limited to 110 ton for extra seaworthiness). At least five Orlyonoks have been built.



The most recent Ekranoplan development in the former Soviet Union is the 400 ton Lun (photo left) which was built in 1987 as a missile launcher. It carried the missiles on top of the fuselage. Recently the Lun has been demilitarised and proposed as a passenger vehicle for 400 passengers. Due to the economical situation in the CIS the development of Ekranoplans has now slowed down and the Russian technology is for sale.

Other design bureaus



Apart from the developments at the Central Hydrofoil Design Bureau, there were other developments too in the former Soviet Union. These are less known, since their WIG vehicles are less remarkable. One such development was the application of the Lippisch configuration by the Central Laboratory of Lifesaving Technology in the Eska design in the sixties. They even built Lippisch vehicles based on an Antonov-2 aircraft and a Blanik glider.
A very successful development is the Volga-2 (photo right) of

the SDPP design bureau. This vehicle has a revolutionary S-shaped airfoil that improves the pitch stability of the Volga. These S-shaped airfoils are now being researched around the world and applied in most new designs. The Volga-2 has recently gone into series production.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

From 1-3 September 1997, a workshop on 'High Speed Body Motion in Water' was held at the Institute of Hydromechanics, Kiev, Ukraine. The workshop was divided in five sessions: hydrobionics, boundary layer flows, supercavitating flows, air-water penetration and control of cavitation. This report gives a summary of the presented lectures. The workshop was intended to improve the contacts between European/American and Ukrainian/Russian scientists and succeeded in this. The presented lectures were theoretical as well as practical and gave more insight in the behaviour of high speed body motion in water. However, still not everything is clearly understood and further research is recommended.

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